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Forecasting Research Division
Technical Report No. 81

Processing and assimilation of automated aircraft data

by
R.S. Bell, N.B. Ingleby and C.A. Parrett

January 1994

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1. Introduction

Automated aircraft data have been available for several years. There are several advantages over manual reporting: observations at more frequent intervals, a reduced likelihood of coding/transmission errors and also greater reporting precision particularly for temperature. A small number of ASDAR-equipped aircraft on trans-oceanic flights have reported for several years (see section 7 for a glossary of acronyms). Automated data from internal Australian flights have also been available for a couple of years in AMDAR code. In the latter case the data have been of very high density around the airports because the systems provide data in the ascent and descent phases of the flight. Because monitoring statistics identified the automated aircraft data as being of good quality, it was utilised within the operational assimilation system without an assessment of impact since it was merely supplementing the already available manual aircraft data.

During 1993, an additional source of automated aircraft data became available from internal flights within the United States. This data is often known as ACARS data. It has similar characteristics to the Australian AMDAR data. The work reported in this note addresses the processing and assimilation of this ACARS data, although it is more generally applicable. Monitoring statistics indicate the ACARS data to be of generally good quality, so we are not questioning its use within the operational system. (Quality control of aircraft data was examined in Ingleby, 1993. Forrester and Human, 1993, compared ASDAR reports with numerical forecasts; the quality of ASDAR reports is probably similar to or slightly better than other automated aircraft reports.) The study was provoked by two questions. The substantial increase in data volumes is beginning to impose a cost overhead on the operational system. In this respect, the gain obtained from the use of the extra data needs to be quantified. We might also consider whether we are processing the automated data in the most efficient manner. The impact of the ACARS data is particularly interesting to identify, because of its geographical location upstream of the UK.

In section 2, we consider the impact of including the ACARS data within the operational system with no other revisions to the system. In section 3, we consider a preprocessing of the data which is designed as a cost saving measure. In section 4, the impact of the preprocessing revisions discussed in section 3 will be considered.

2. Impact of ACARS data

We performed a two day assimilation experiment from 12GMT 14 December 1992. Forecasts out to 48 hours were run from each 00GMT and 12GMT analysis (four in all). The volume of aircraft data during this period is given in Figure 1, which shows data volumes for three code types, AIREP, AMDAR data in character code, AMDAR data in BUFR code in each 6 hour period. The first two code types were being used by the operational control run and the third code type (comprising of the ACARS data) was included additionally in the test run. In Figure 1, we note that the BUFR AMDAR data provides about 2000 extra reports each 6 hour period, which amounts to a doubling of the data volume from aircraft data.

The first results from this experiment were disappointing. There appeared to be almost no impact. It was only when the maps of data distribution were examined, that we appreciated

the extent of the AIREP coverage over the USA, which made the additional BUFR AMDAR data effectively redundant. Figures 2-4 give the coverage of AIREP, character AMDAR and BUFR AMDAR data respectively for a particular 6 hour period and for pressure levels in the range 150-400hPa. In Figure 2, we see that as well as obtaining AIREPs from the trans-oceanic routes over the North Pacific and North Atlantic, we are also getting many reports over the USA. Figure 3 shows that the character AMDAR coded reports are predominantly Australian. Figure 4 shows the BUFR AMDAR coded reports are mostly US. It is clear from these charts that the potential for duplication is great. In fact, the AIREPS over the USA in Figure 2 were found to be ACARS data recoded and retransmitted as AIREPs by another centre. As well as generating duplicate information and making the additional AMDAR data redundant, it should be noted that the data volumes tabulated in Figure 1 are not a true reflection of the number of measurements made. Figure 5 is the same as Figure 4 but for the pressure range 500-1000hPa, to illustrate the high density of horizontally coincident reports at airports. We address this point again in section 3.

To provide a more effective control run we repeated the operational run with all aircraft data over the USA and Canada removed. The forecasts were verified over the Atlantic sector (an area approximating to the traditional "Area 2"). Table 1 demonstrates the degree of improvement obtained for each of the three forecast periods. We see the biggest signal in the later forecast stages as the information is advected downstream into the verification area. Reductions in scores of the magnitude obtained at T+48 (of order 3%) are highly significant, representing as they do the expected annual improvement in operational scores (according to the Met Office business plan) in a single change to the system.

	T+12	T+24	T+48
surface pressure	0.5	1.3	3.6
sonde temperatures	0.1	0.1	2.4
airep temperatures	1.8	0.7	2.7
satellite temperatures	-0.8	0.1	1.3
sonde winds	0.8	1.6	3.0
airep winds	2.0	2.4	4.0
ship surface winds	0.0	-0.4	2.6
sonde humidity	0.1	0.9	1.0

Table 1 Percentage improvement in rms scores over "area 2" when "amdar" data is included. (Mean of 4 cases from 15th-17th December 1992.)

Table 2 shows the comparative verification results at T+48. We note a 0.5m/s improvement in verification scores for aircraft wind levels and a 0.25hPa improvement in surface pressure scores as being the most notable changes.

	no "amdars"	incl "amdars"
surface pressure	6.64	6.40
sonde temperatures	2.94	2.87
airep temperatures	2.86	2.78
satellite temperatures	2.79	2.75
sonde winds	10.18	9.87
airep winds	13.98	13.42
ship surface winds	11.63	11.33
sonde humidity	27.87	27.58

Table 2 RMS scores for "area 2" with and without "amdars" at T+48. (Mean of 4 cases from 15th-17th Dec 1992.)

Typical analysis differences are shown in Figure 6, which shows the comparative 250hPa wind analyses at the end of the experiment, with associated difference charts. We see significant differences in the analysis of the jet emerging from North America and in the flow around the sharp upper trough in mid-Atlantic. The subsequent forecast evolution is given in Figure 7 in the same format. The analysis differences have amplified and advected downstream towards the UK.

Both the SW'ly jet leaving Newfoundland and the positioning of the cutoff low at 25N 55W verify better in the run with "amdars", as we can see from the expanded forecast comparisons in Figures 8 and 9 which have both wind speed and geopotential height forecasts with verifying aircraft reports superimposed. In figure 8, the 110 knot forecast isotachs give the clearest indication of the phase error in the control (left chart), where of 5 reports of 120 knots or more, one is forecast less than 110 knots and 2 less than 100 knots. The test run has 3 of those reports forecast to be greater than 110 knots and the other 2 to be in the range 100-110 knots. In figure 9, we focus on the other main area of difference where observations were available to verify. The cutoff low to the west of the Caribbean is more correctly positioned in the test run (right chart), if we look at the 3 southerly wind reports (all in excess of 40 knots) near the cutoff, they fall inside the 20 knot isotach in the control whereas only 1 of the 3 falls within the 20 knot isotach in the test.

3. A revision to AMDAR observation processing - vertical profiles

The increasing expense of using all the individual observations has already been noted. One option would be to thin the AMDAR observations, this does not make best use of the data, and a better option is to combine several observations into 'superobservations'. Where the data density is much higher than can be fully utilised by the data assimilation superobbing can be an economic way of using the data to almost its full effect. Two questions arise when considering superobbing: should we combine observations from different aircraft? and

should we combine observations into vertical profiles?

There are distinct advantages to processing different aircraft separately: the reports from a particular aircraft can be easily checked for internal consistency before checking against other aircraft; we effectively retain full time resolution which may be important in rapidly changing situations; if the superobs are archived then error characteristics can be deduced for individual aircraft.

Combining observations into a vertical profile has cost benefits within the current operational analysis system. In the analysis correction scheme both single- and multi- level observations are processed into a vertical profile of increments before the horizontal analysis takes place. This has the important consequence that the time taken to assimilate a multi-level observation is similar to that taken to assimilate a single-level observation (about 0.1 second per observation).

It was decided to combine aircraft reports into vertical profiles, partly for cost reasons. It was also hoped that this would speed convergence within the assimilation and hence improve the fit to vertical detail in the aircraft data.

The aircraft are sorted by callsign, observation type and time. Within each flight ascent and descent portions, 'profiles', are identified: at least 3 consecutive reports below 450 hPa, terminated by either a report above 450 hPa, a gap between reports of 20 minutes or a turning point in pressure. (Code for a whole flight check was included, but it has proved difficult to distinguish model and observation problems and it is not used operationally.) The profiles are then formed into radiosonde-lookalike observations. The processing starts with the lowest report and finishes if the horizontal displacement exceeds a preset value (100 km). Radiosonde profiles are currently treated as vertical ignoring the horizontal movement during the ascent, for this reason a limit on the horizontal displacement was necessary and it should be roughly consistent with the analysis resolution (which tends to be coarser than the model resolution).

Radiosondes are averaged over model layers in a pre-analysis step (Ingleby and Parrett, 1994). For the aircraft data the model P* at the position of the lowest observation is used in the calculation of model layer boundaries. The temperatures are integrated to give layer mean thicknesses (the method used does not produce a value if the model layer is only partly covered by the observations). For winds a straightforward layer mean is used (provided that the model layer is at least half covered with observations). The profiles are then buddy checked against other profiles (usually above the same airport) and any nearby radiosondes. In the assimilation the values are used only at that model layer (except for the top and bottom of the profile) whereas all single level observations have their increments spread in the vertical.

Preliminary tests were carried out on data from 24 March 1993. When the maximum horizontal displacement was 150 km all the profiles examined reached to about 400 hPa (the highest level below the cut-off of 350 hPa used in these tests). The ascent to/descent from this level takes the aircraft between 10 and 20 minutes (occasionally longer). From the Australian aircraft there were usually 14 or 15 reports in the profile, being particularly dense near the surface. The American ACARS data had fewer reports per profile. The

results suggested that the profiles would save 41% of the cost of assimilating aircraft data, this was reduced slightly to 38% when the maximum horizontal displacement was reduced to 100 km. Those figures were for character codes only, adding BUFR data reduced the saving by 3-4% because the ACARS data was better represented in the binary code.

The saving in the next section is only about half of that expected from these preliminary results. This is partly due to lowering the cut-off to 450 hPa, but appears to be mainly because many duplicates have been eliminated by switching entirely to BUFR data for the automated aircraft reports.

The numbers of pairs of cruise level reports within ten minutes of each other was also calculated. Depending on the options used a saving of 13-17% was indicated if they were combined into superobs. In level flight the spacing between observations is typically 7 minutes, about 60 km at a speed of 500 km/h. Allowing combination of all observations in a fifteen minute window suggested savings of 21-25%, however this interval was felt to be too long for serious consideration. No further work was done on this topic.

4. The impact of vertical profiles

In order to test the impact of combining aircraft observations from ascent/descent phases into profiles, a 4-day case study was run, for the period 00Z 8th to 00Z 12th October 1993. Data for the global Unified Model were assimilated for the four days, with seven 3-day forecasts spawned off, one every 12 hours (the first one 24 hours into the assimilation sequence). The analyses and forecasts have been verified against the operational observation files and compared with results from a control (pseudo-operational) run.

The upper cut-off for the profiles was set at 450hPa, and the maximum range within which aircraft reports were combined was set at 100km. This produced an average of 63.5 profiles per 6-hour time-window, from 606 aircraft reports (i.e. an average of nearly 10 reports per profile). The average number of aircraft reports per 6 hours was 2926, which meant that for the aircraft profile runs there was a reduction in aircraft reports presented to the assimilation of 21%, while there was an increase in the number of (sonde + aircraft) profiles of 12% for winds and 20% for temperatures. A typical distribution of the aircraft profiles for one 6-hour time-window is shown in Figure 10; it is for model level 4 (eta = 0.87), where the largest number of profiles were found (< 10% of the profiles were either entirely above or entirely below this level). All of the profiles were either over the USA (ACARS data) or over Australia (AMDARs).

The average verification scores for the 7 analyses and forecasts of the aircraft profile and control runs, are compared in Table 3. For the three areas of the globe split at 30N and 30S (3a, 3b and 3c), there is a null impact overall, with some variables/areas/forecast times verifying slightly better and some slightly worse. In most instances the differences are less than 0.5%, which is probably not significant given the small number of cases. The generally slightly poorer fit to aircraft data at T+0 (and possibly T+24), is due to the verification being against the operational observations, i.e. the single level aircraft data, which naturally favours the operational run.

For the Atlantic sector (3d which is approximately the operational verification "area 2"), after a slightly closer fit to sonde wind and temperature data at T+0, there is a small but noticeable deterioration from T+24, particularly in fit to surface pressure (although still < 2% at T+72).

(a) North of 30N	T+0	T+24	T+48	T+72
Surface pressure	0.0	-0.2	-0.3	-0.1
Sonde temperatures	0.2	-0.1	-0.1	-0.2
Aircraft temperatures	-0.3	-0.1	-0.5	-0.4
Satellite temperatures	0.0	0.0	-0.3	-0.3
Sonde winds	0.2	-0.1	-0.1	-0.1
Aircraft winds	-0.2	-0.2	0.1	-0.3
Ship surface winds	0.0	0.0	-0.1	-0.3
Scatterometer winds	0.0	0.1	miss	-0.7
Sonde humidity	-0.2	0.0	0.0	-0.1

Table 3a % improvement in rms verification scores for 7 forecasts with aircraft profiles (00z 9th - 00z 12th October 1993) for Area north of 30N

(b) 30N - 30S	T+0	T+24	T+48	T+72
Surface pressure	0.3	0.1	0.0	0.3
Sonde temperatures	0.3	0.1	0.0	0.0
Aircraft temperatures	-0.5	0.0	-0.1	0.7
Satellite temperatures	0.0	0.1	0.0	0.1
Sonde winds	0.3	0.0	-0.1	0.1
Aircraft winds	0.1	0.2	0.1	0.2
Ship surface winds	0.1	0.1	-0.4	-0.2
Scatterometer winds	-0.1	0.1	miss	0.0
Sonde humidity	0.3	0.3	0.2	-0.2

Table 3b as 3a but for Area (30N-30S)

(c) South of 30S	T+0	T+24	T+48	T+72
Surface pressure	0.1	0.3	0.1	-0.2
Sonde temperatures	1.2	-0.1	-0.2	-0.3
Aircraft temperatures	-0.3	0.2	-0.9	-0.4
Satellite temperatures	0.1	-0.1	-0.1	-0.5
Sonde winds	1.2	0.1	0.0	0.1
Aircraft winds	-0.3	1.1	0.7	0.9
Ship surface winds	0.6	0.0	-0.1	-0.3
Scatterometer winds	0.0	0.1	miss	-0.5
Sonde humidity	1.0	0.1	-0.3	-0.2

Table 3c as 3a but for Area south of 30S

(d) 30-70N,0-120W	T+0	T+24	T+48	T+72
Surface pressure	0.1	-0.7	-1.3	-1.7
Sonde temperatures	0.6	-0.3	-0.2	-0.5
Aircraft temperatures	-0.3	-0.1	-0.6	-0.6
Satellite temperatures	0.0	0.0	-1.0	-0.9
Sonde winds	0.6	-0.2	-0.1	-0.2
Aircraft winds	-0.1	-0.3	0.2	-0.3
Ship surface winds	-0.1	0.0	-0.3	-0.5
Scatterometer winds	0.1	0.3	miss	-0.5
Sonde humidity	-0.3	0.0	0.1	0.0

Table 3d as 3a but for 'Area 2' (30-70N,0-120W)

An example of the differences between the two runs is shown in Figure 11, for the forecasts from 00Z 12th October (after the full 4 days of separate assimilations). Figures 11(a) and 11(b) show that the differences in the T+72 250hPa wind speed, in the two areas downstream of the aircraft profile data, were no larger than 2 knots anywhere. The largest differences in surface pressure for the area in Figure 11(a) were about 1hPa for this case.

For the assimilation with aircraft profiles, there was a reduction of 5% in CPU time. Typically, one day's global assimilation on the Cray Y-MP takes about 10 minutes elapsed time, so implementing the aircraft profiles operationally would currently save about 30 seconds elapsed time per day. With an expected increase in aircraft data, the saving in the future will probably become more significant.

5. Conclusions

Automated aircraft data is of a high quality and we have shown that it has a positive impact on both the assimilations and the forecasts, with a substantial 3% improvement in T+48 verification scores for "Area 2". This data is currently being used operationally at the Met Office, but the assimilation of single-level aircraft data is expensive in terms of computer time. As a cost-saving measure, we have developed a method of combining reports from the ascent or descent phases of aircraft flights into "aircraft profiles". Currently, the saving in computer time through the use of aircraft profiles is small but not insignificant at 5% of total assimilation time. However, due to the slight degradation in the 2-day and 3-day forecasts for "Area 2", it has been decided not to implement the profiles operationally now. We may re-assess the situation in about a year's time, if the volume of automated aircraft data increases substantially.

6. References

D.A.Forrester and J.Human, 1993: Verification of NWP model wind and temperature forecasts using ASDAR reports. Forecasting Research Division Technical Report No. 72.

N.B.Ingleby, 1993: Quality control of aircraft data: an intercomparison, case studies and improvements. Forecasting Research Division Technical Report No. 72.

N.B.Ingleby and C.A.Parrett, 1994: Quality control of atmospheric data. Unified Model Documentation Paper No. 32. Version 3.

7. Glossary

ACARS - ARINC Communications Addressing and Reporting System. A system for receiving messages in individual airline format and forwarding them to the meteorological community. The system is provided by the ARINC company under contract, and processes reports over the US and nearby. It currently takes observations from three airlines, soon to be extended to five. (There is a similar system called AIRCOM operated by SITA over Australia, parts of Asia and Europe. Some Australian international flights store information on board the aircraft and transmit it as the aircraft approaches Australia.)

AMDAR - Aircraft Meteorological DAta Relay. A character code used for transmitting automated aircraft data. In this report 'AMDAR' has been used loosely to refer to automated aircraft data whether received in character or binary code.

ASDAR - Aircraft to Satellite DAta Relay. A hardware system used to transmit meteorological data. Only about eight ASDAR systems are operational worldwide at any time, over half of them on British Airways aircraft. The code in which they reported was also known as ASDAR until it was replaced by the slightly more general AMDAR code.

BUFR - Binary Universal Form for the Representation of meteorological data.

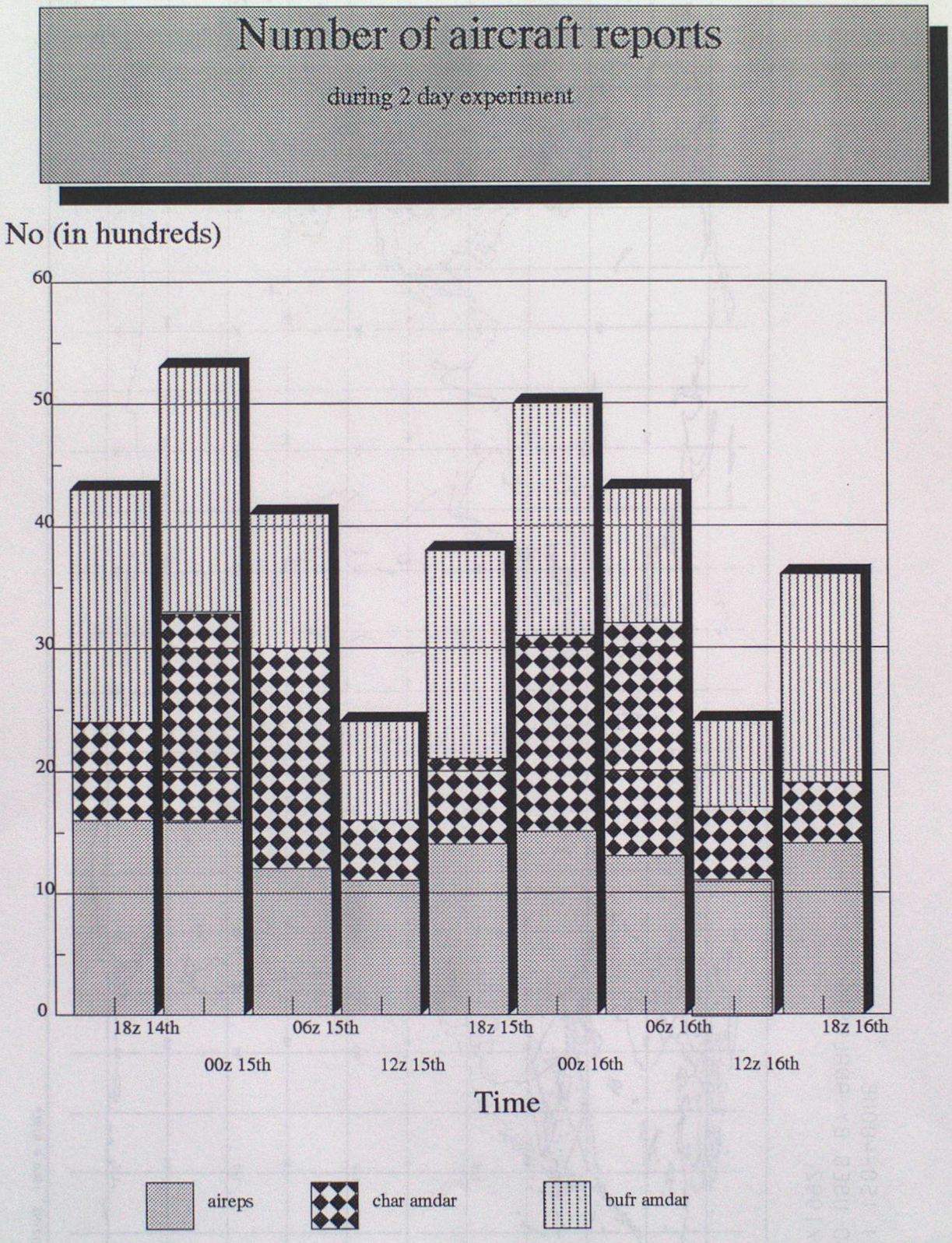


Figure 1: No of aircraft reports per 6 hours during experiment

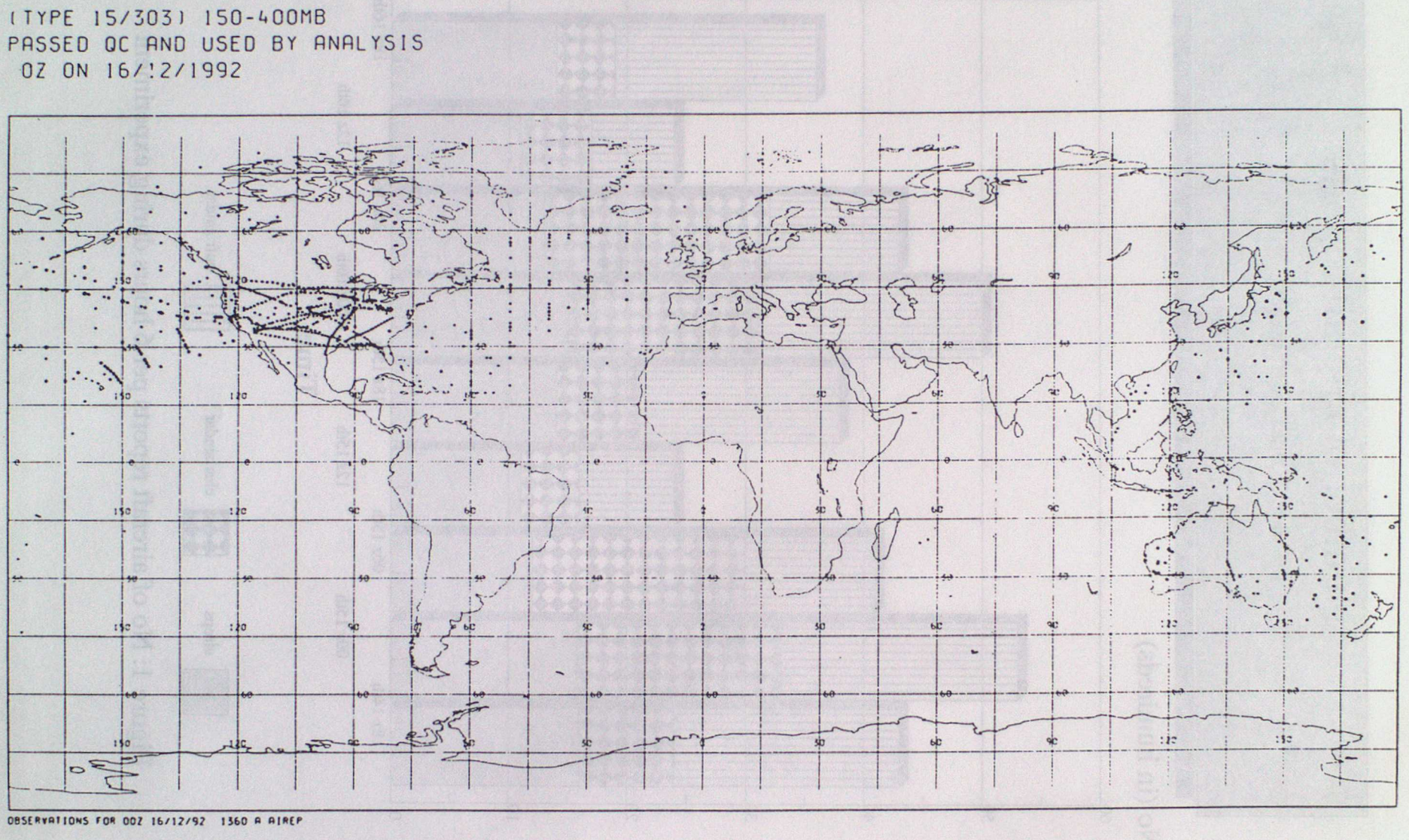


Figure 2: Distribution of aircraft reporting AIREP code
(6 hour window around 00GMT 16/12/92, pressure band 150-400hPa)

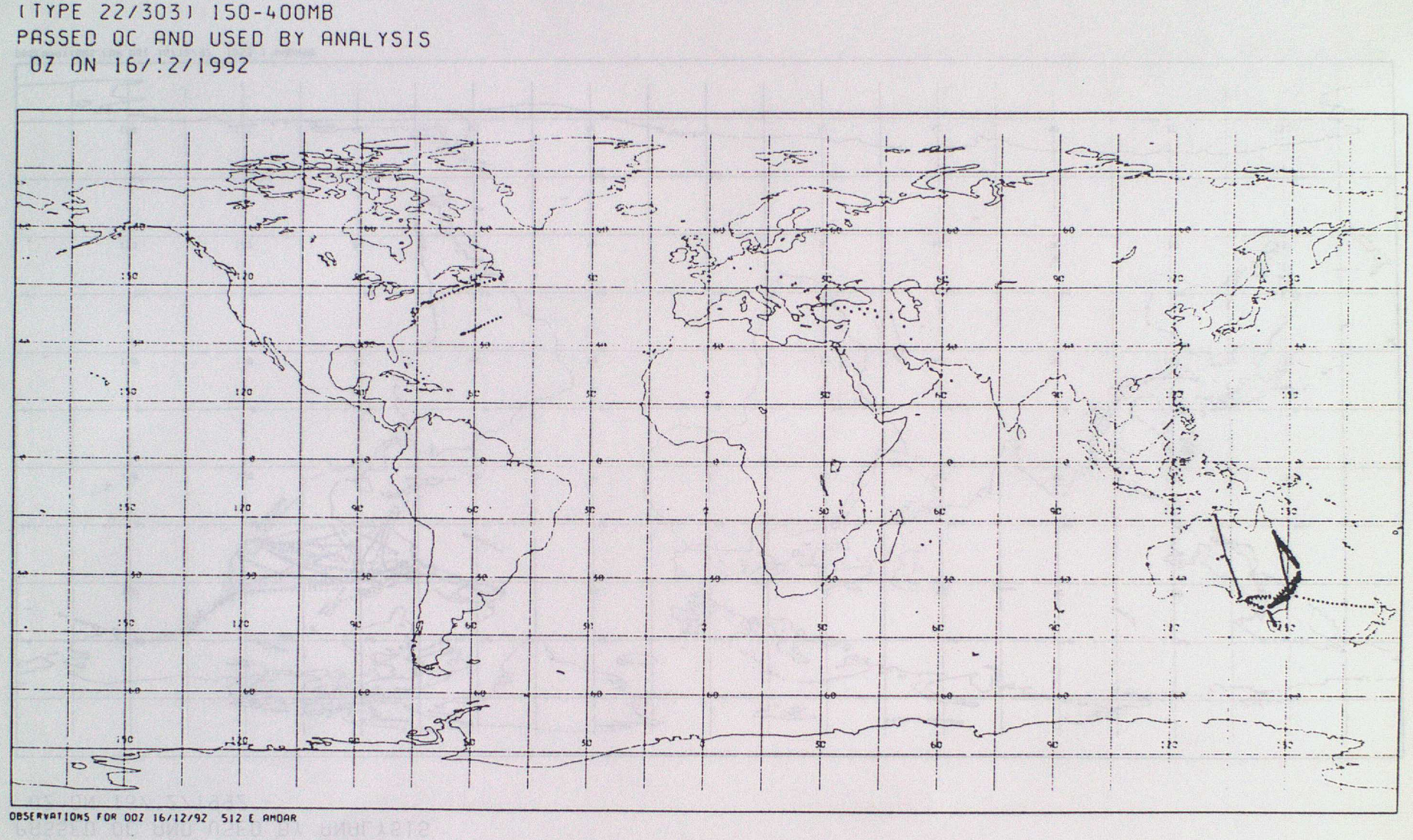


Figure 3: Distribution of aircraft reporting character AMDAR code
(6 hour window around 00GMT 16/12/92 pressure band 150-400hPa)

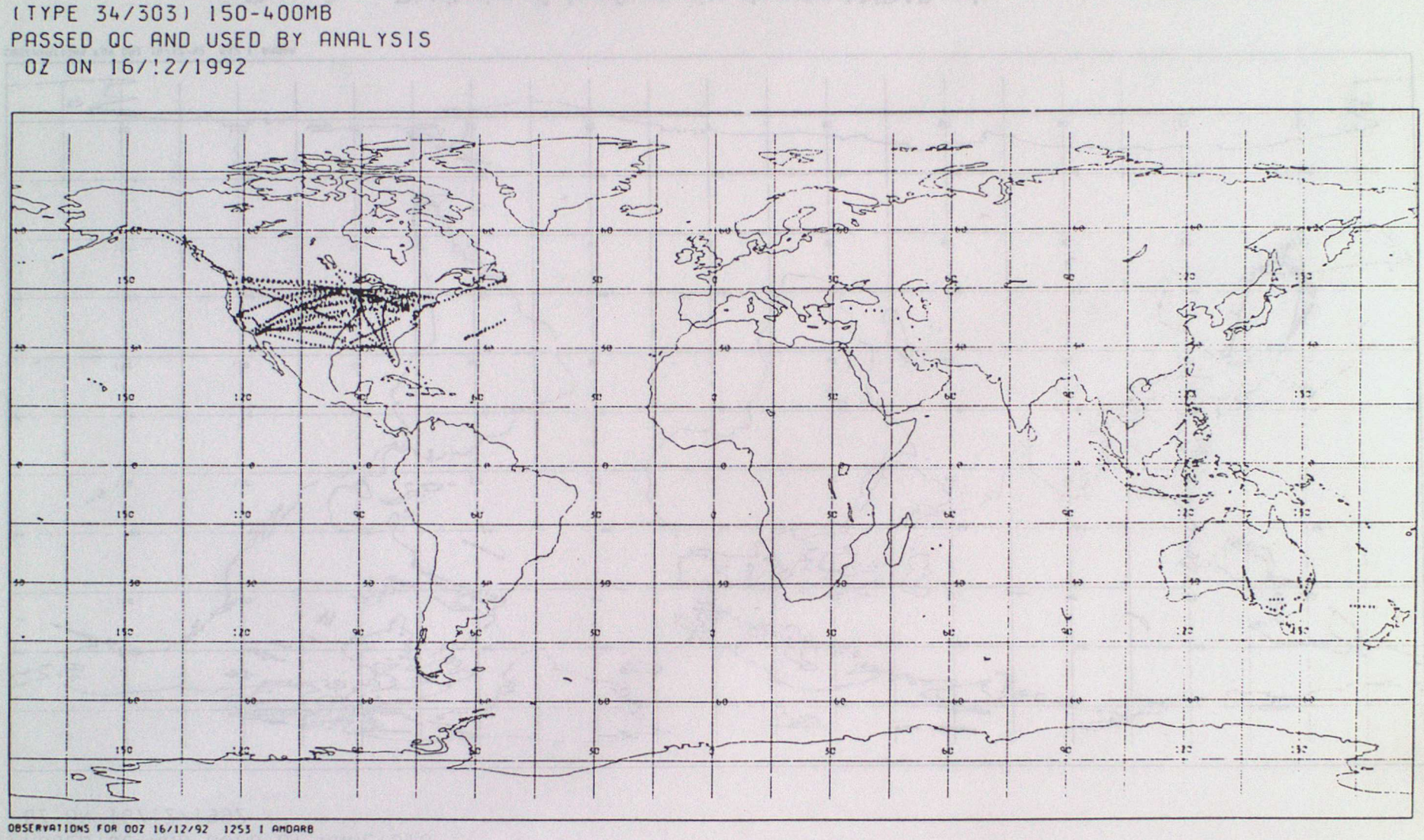


Figure 4: Distribution of aircraft reporting BUFR AMDAR code
(6 hour window around 00GMT 16/12/92 pressure band 150-400hPa)

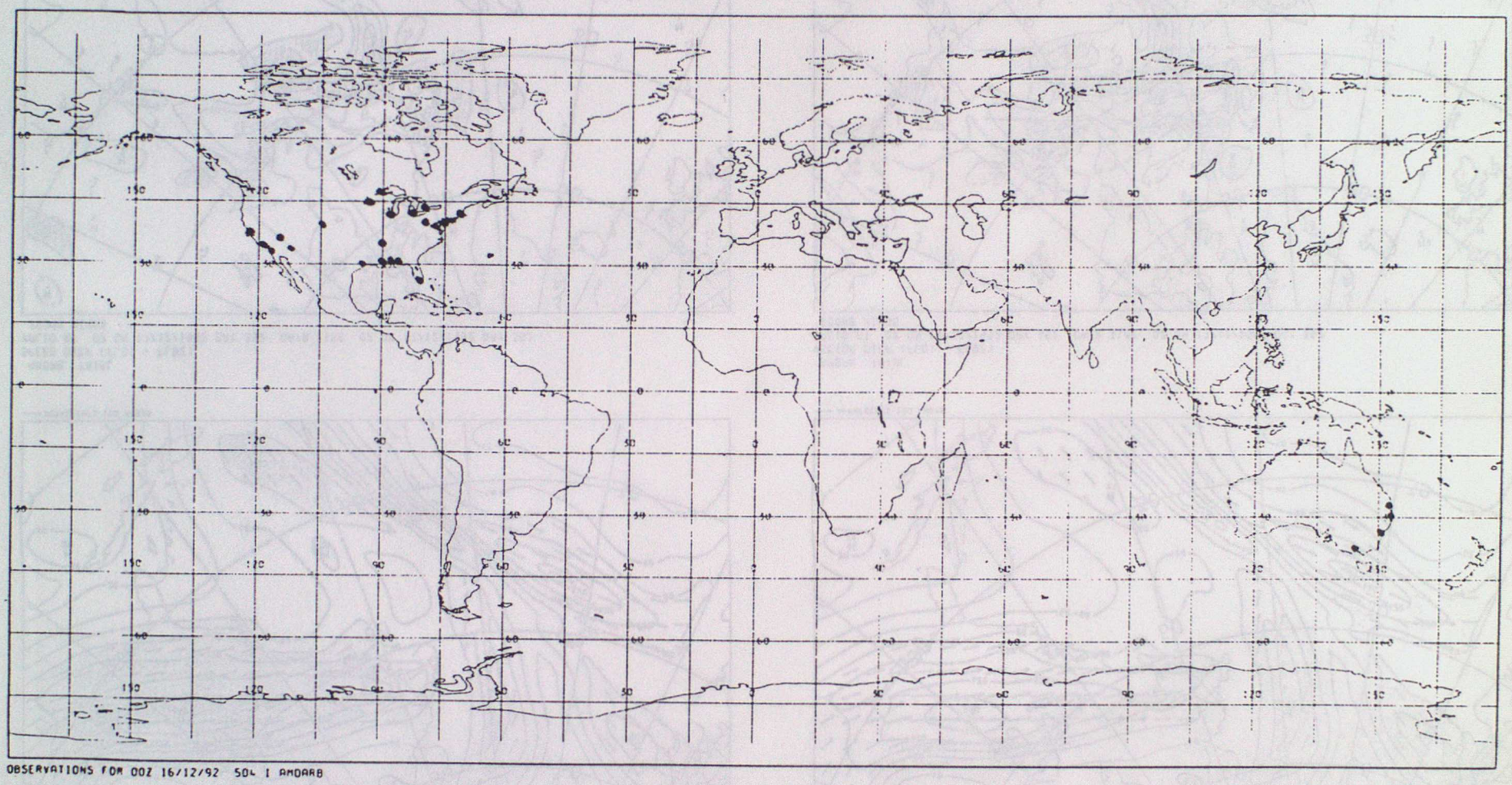


Figure 5: Distribution of aircraft reporting BUFR AMDAR code
(6 hour window around 00GMT 16/12/92 pressure band 500-1000hPa)

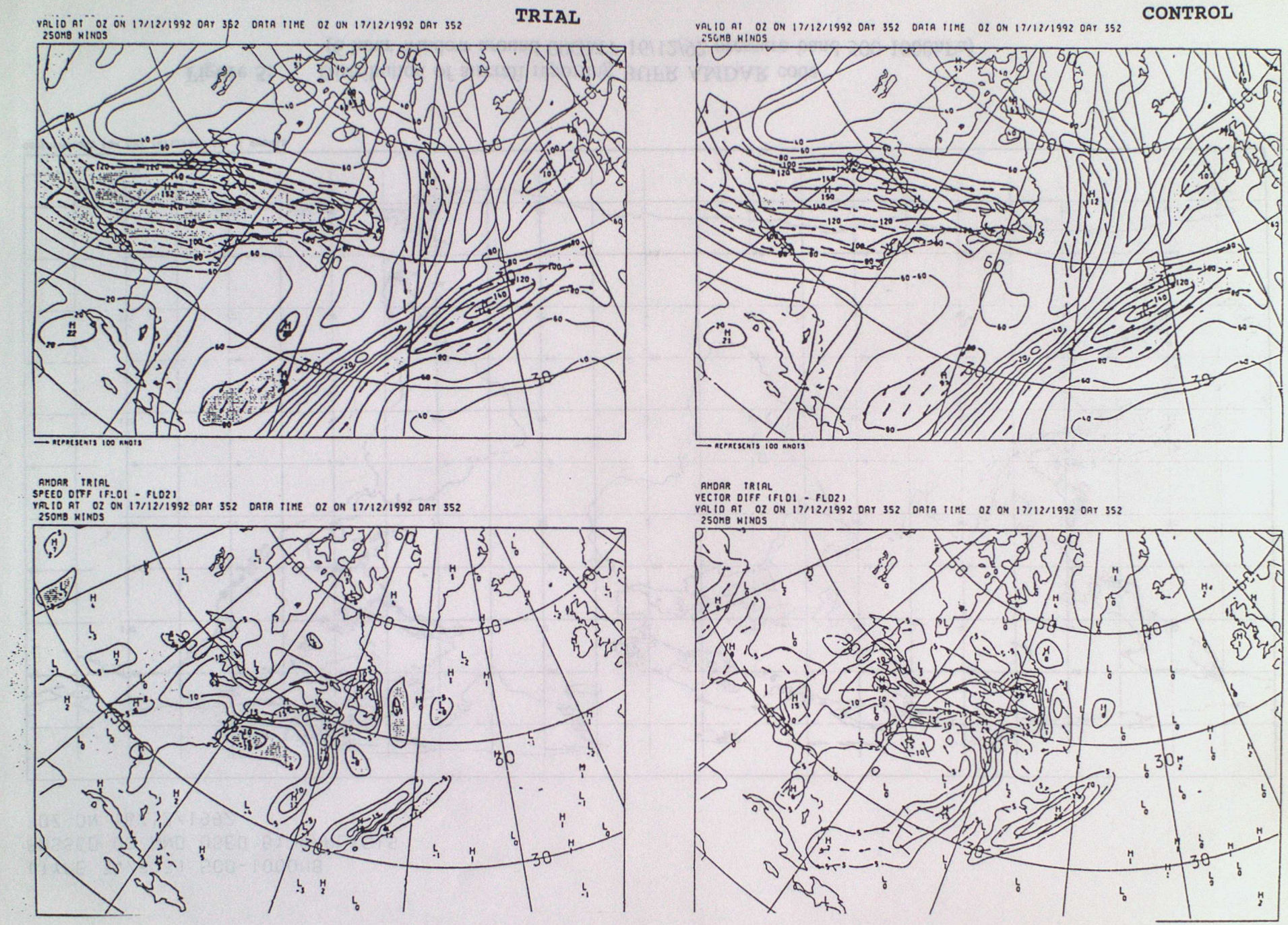


Figure 6: 250hPa wind analysis comparison after 2 day assimilation (00GMT 17/12/93)
top left is with automated aircraft data; top right is control
bottom left is speed difference; bottom right is vector wind difference

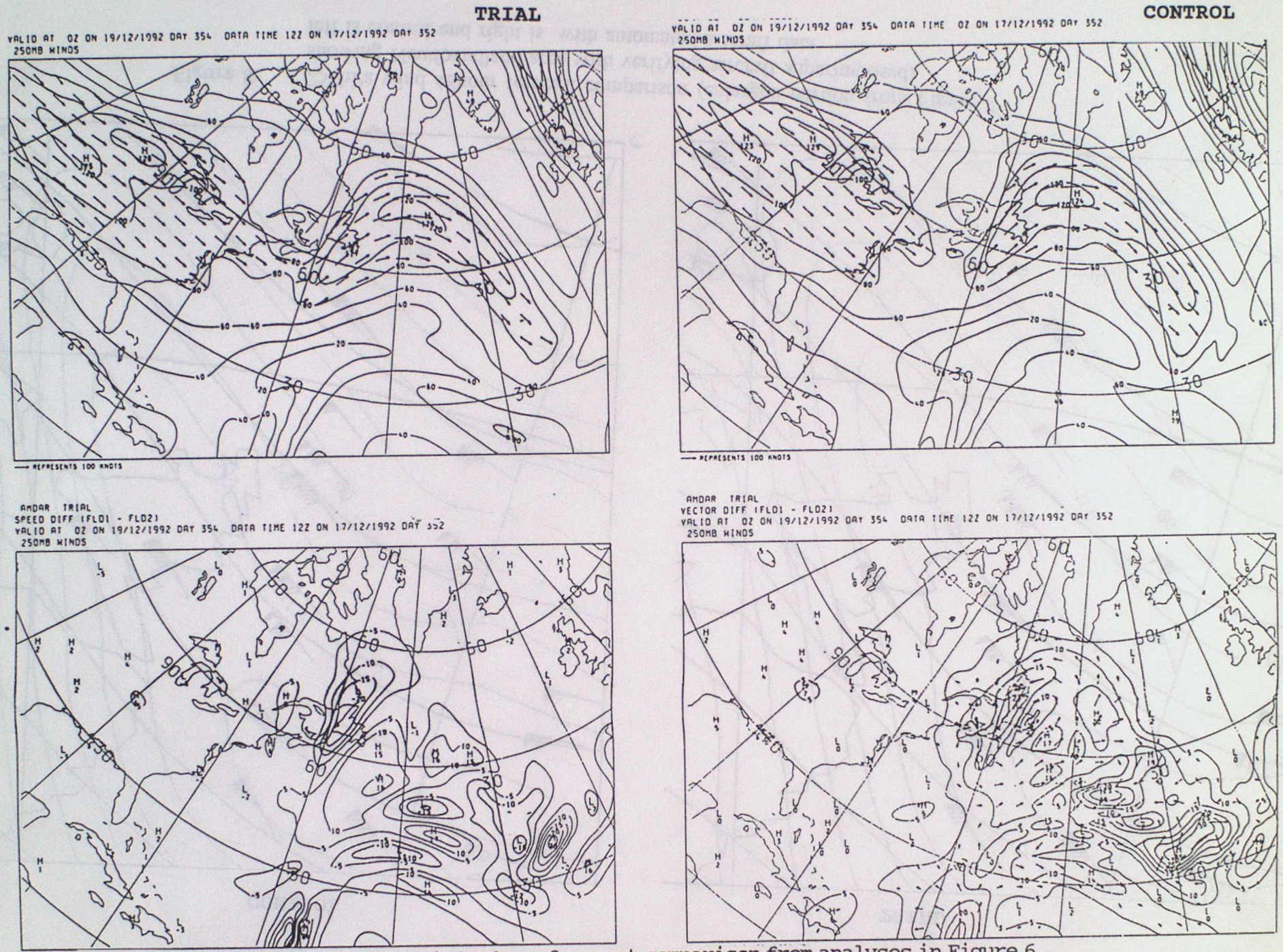


Figure 7: 250hPa wind 48hour forecast comparison from analyses in Figure 6 top left is with automated aircraft data; top right is control bottom left is speed difference; bottom right is vector wind difference

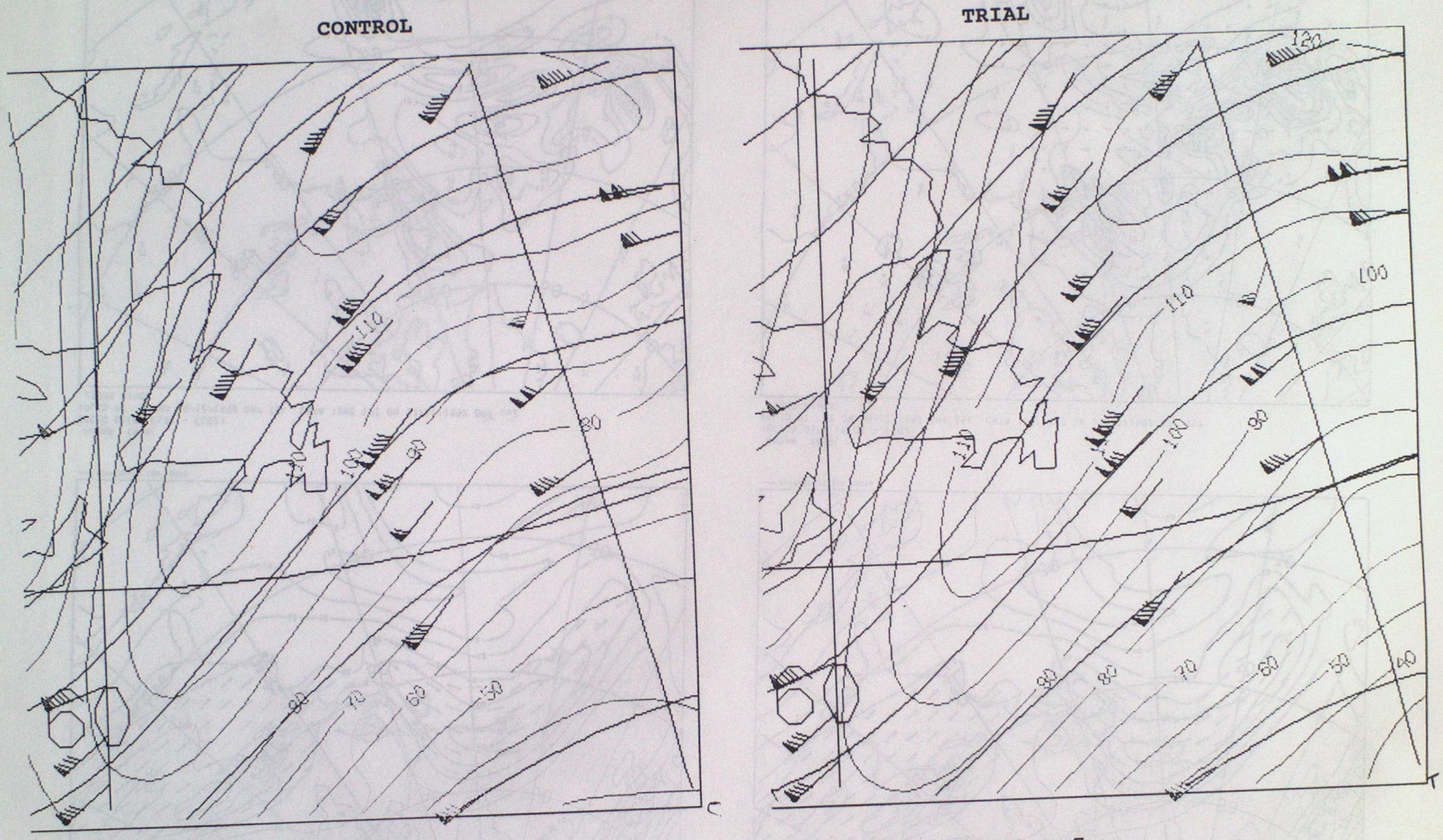


Figure 8: 250hPa wind 48hour forecast comparison (enlarged portion from Figure 7 showing Newfoundland area with verifying aircraft superimposed)
left is control and right is with automated aircraft data

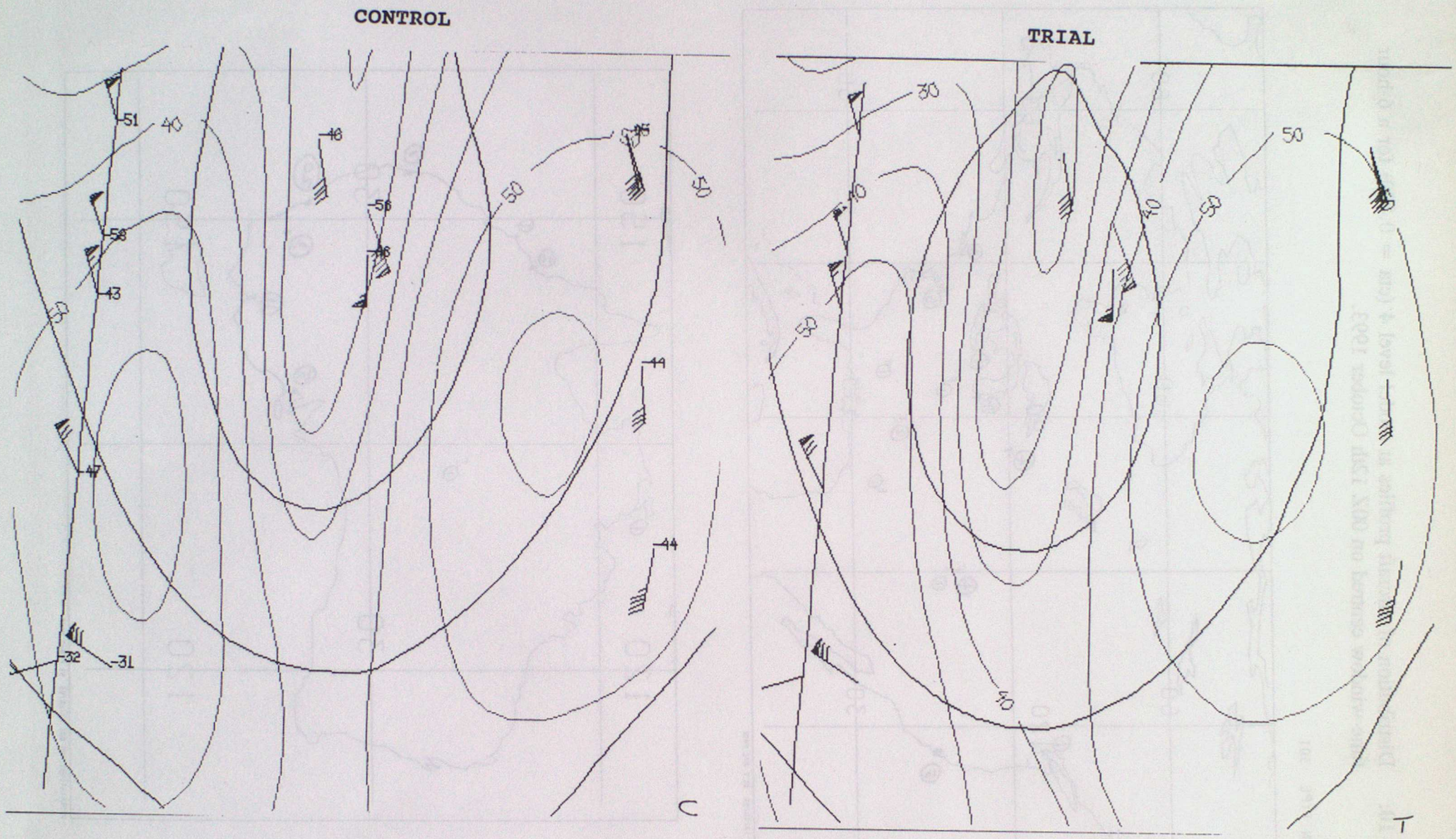
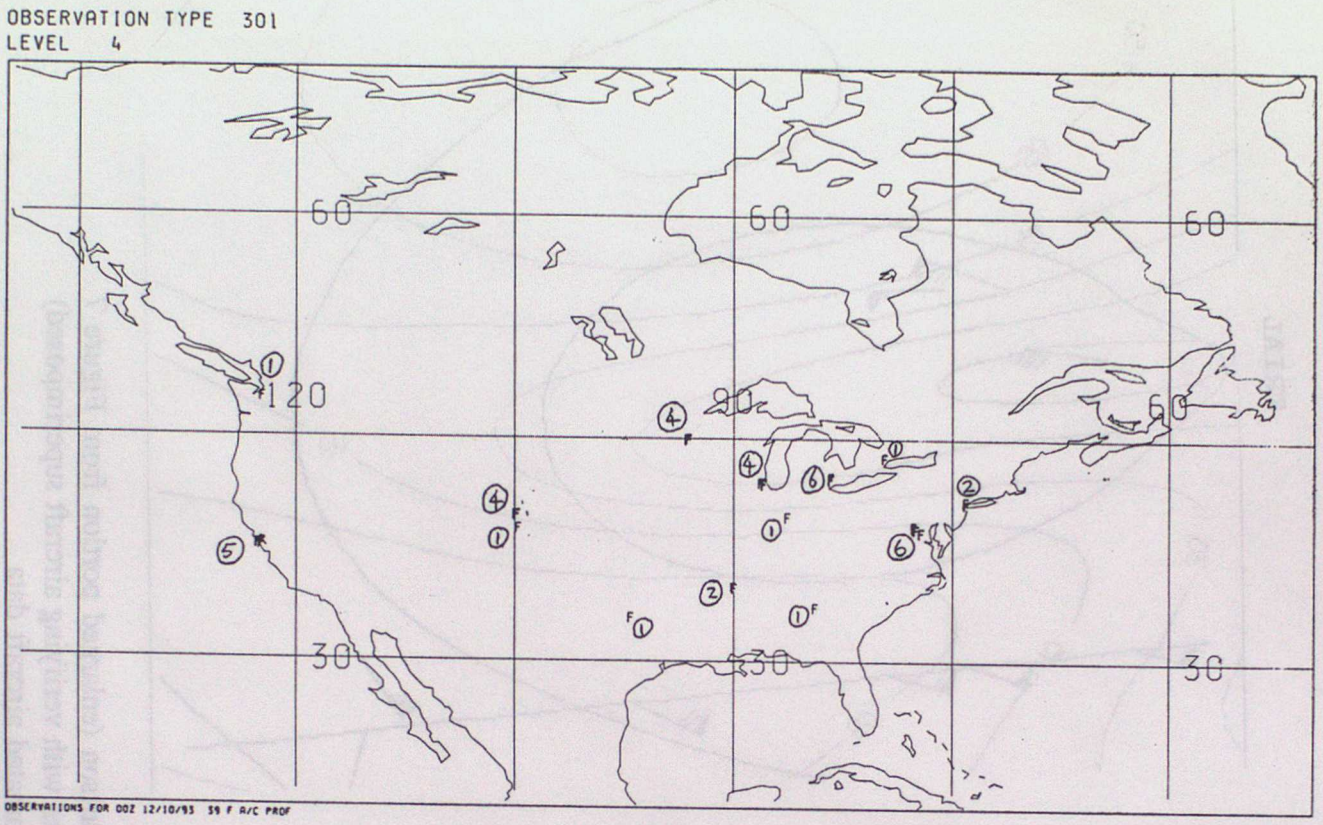


Figure 9: 250hPa wind 48hour forecast comparison (enlarged portion from Figure 7 showing trough east of Caribbean area with verifying aircraft superimposed) left is control and right is with automated aircraft data

Figure 10: Distribution of aircraft profiles at model level 4 (eta = 0.870) for a 6-hour time-window centred on 00Z 12th October 1993.



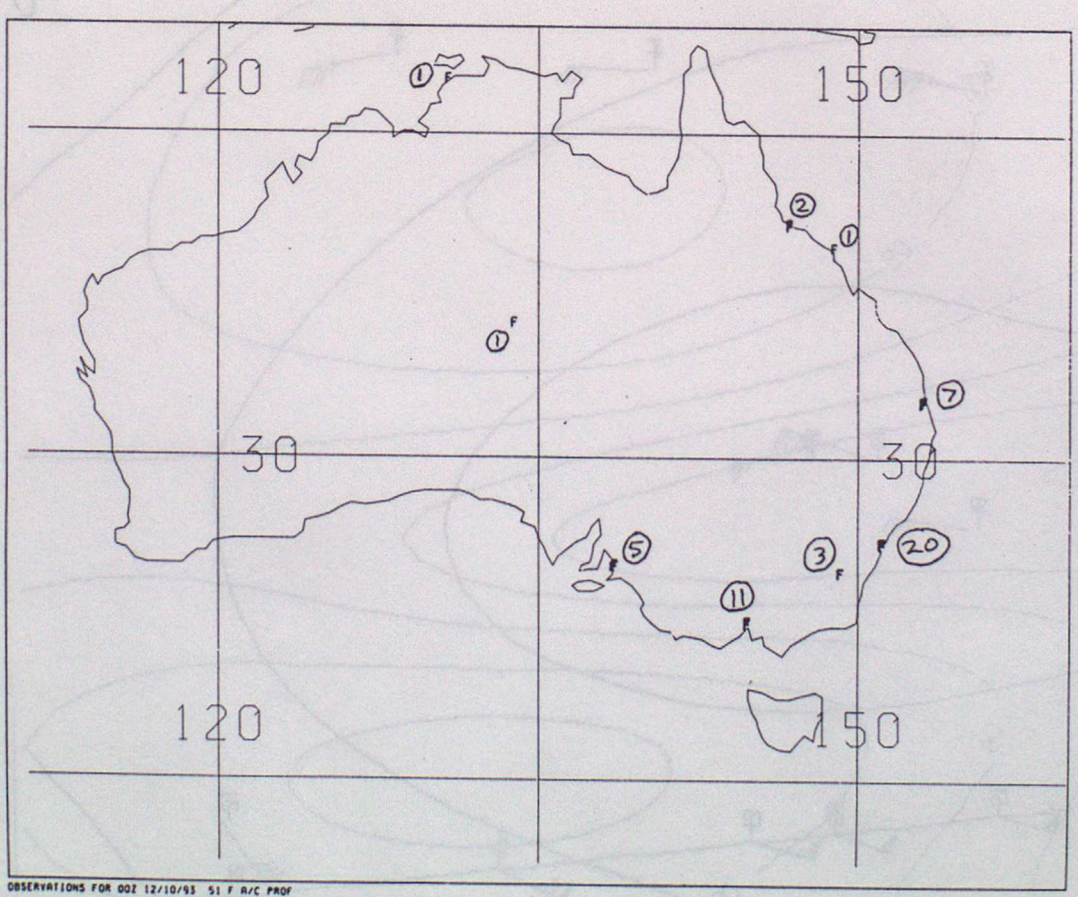
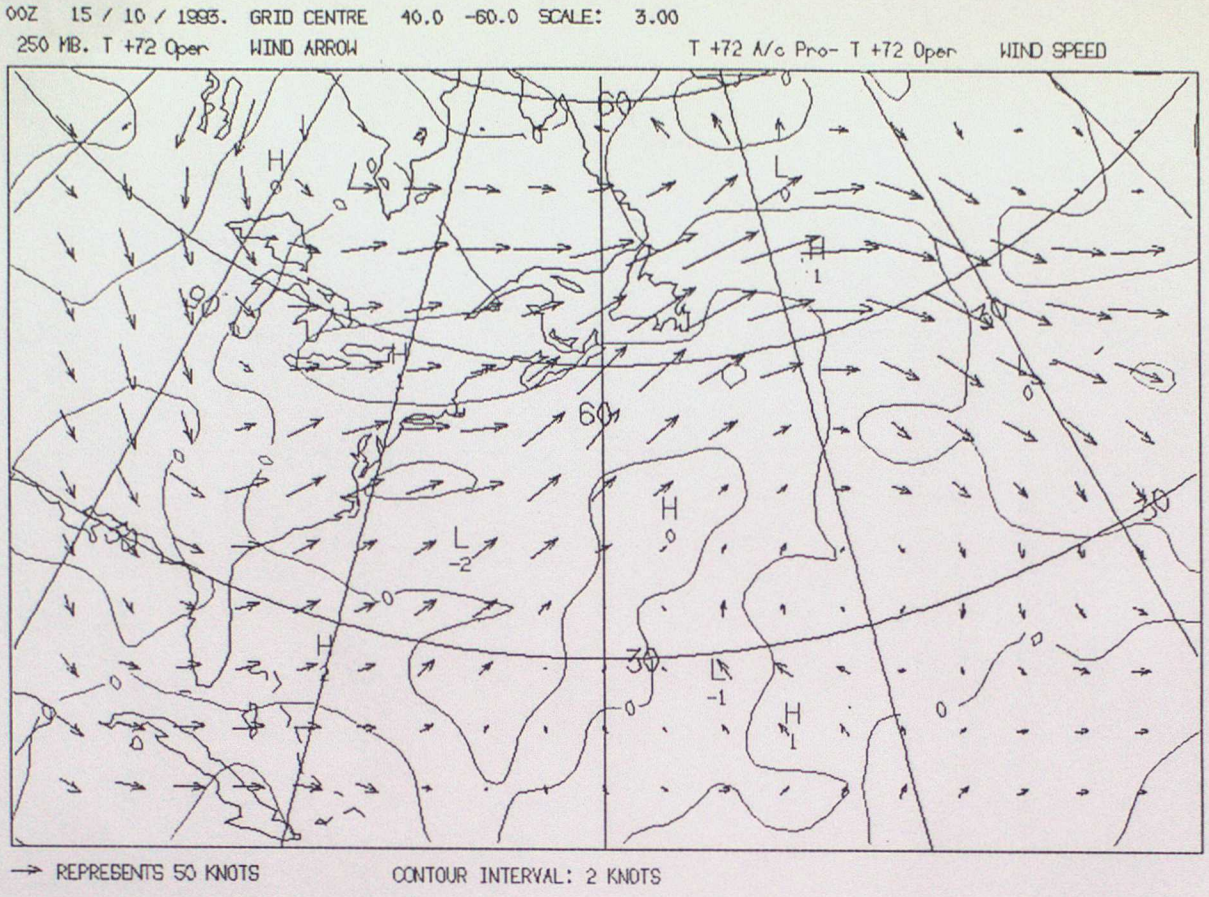
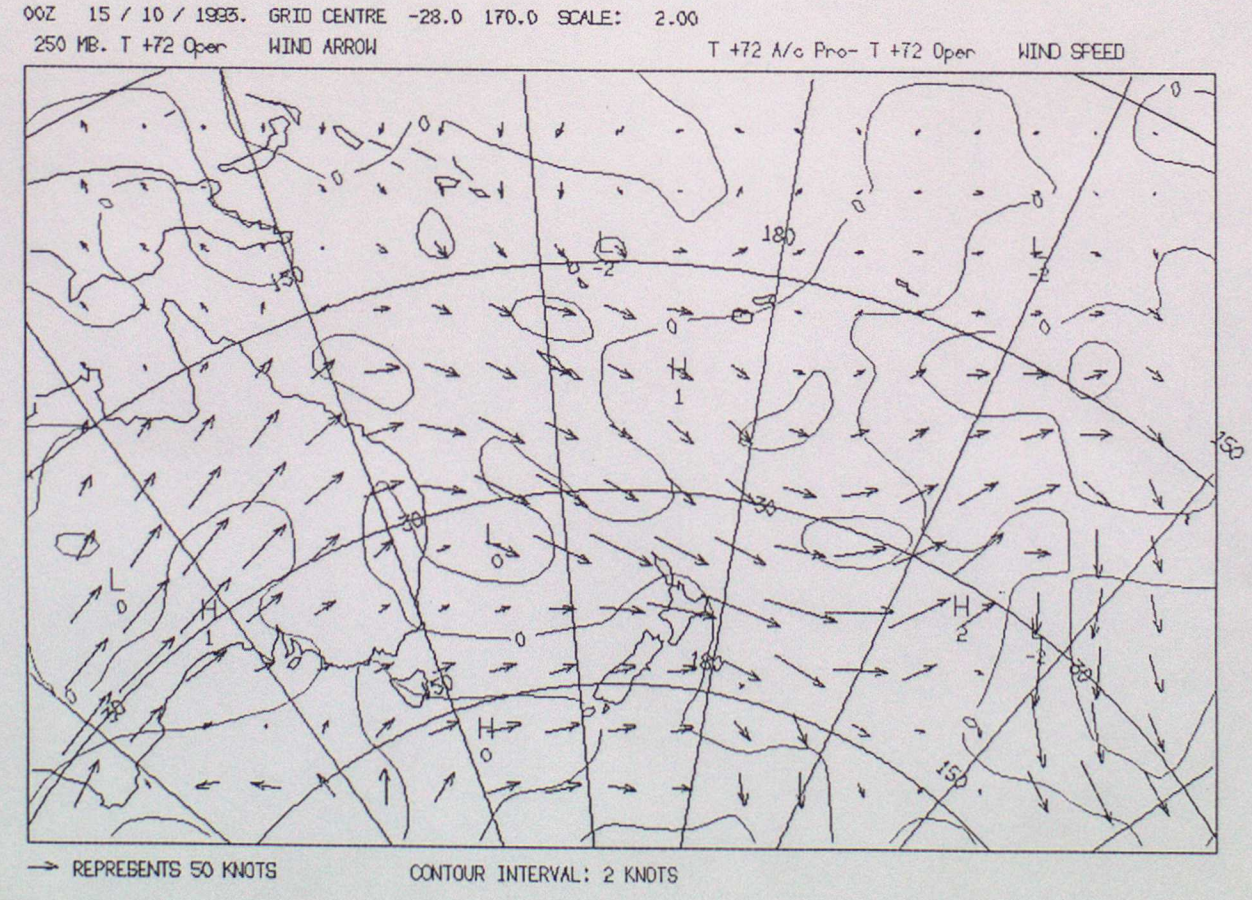


Figure 11: 250hPa wind 72hour forecast differences (aircraft profile run - control run). Also shown, are the operational wind arrows.

(a)



(b)